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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
ECOM-5801

AN ALL DIGITAL AUTOMATED WIND MEASUREMENT SYSTEM

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ECOM

UNITED STATES ARMY ELECTRONICS COMMAND - FORT MONMOUTH, NEW JERSEY 07703

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

In addition to supplying basic meteorological information, vectored wind velocity measurements are essential to the analysis of small caliber ballistic trajectories, optical wave propagation in the lower atmosphere, and wind shears and vorticies. Conventional electromechanical methods, using velocity-to-direct current converters, are often unsatisfactory when integrated into a multisensor array over long path lengths. An all digital system capable of

(cont on p1473B)

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ABSTRACT (Cont) (see p 1473 A)

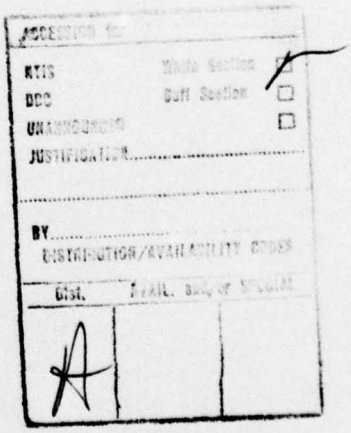
operating as an array over long path lengths has been developed. The system is totally automated. By use of complete metal oxidized semiconductors (CMOS) signal processing remote data acquisition stations, operated under microprocessor control, reliable and accurate asynchronous data transfer has been obtained.

A

1473 B

PREFACE

The authors express their gratitude to Mr. W. Hatch and Mr. D. Favier, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, for their technical assistance.



CONTENTS

INTRODUCTION

Vectored wind velocity information is needed to accurately quantify high velocity ordinance ballistics, scattering of high energy lasers, optical communication data rates in lower atmospheric scintillation, aircraft vortex motion, and so forth. Due to the physical size of these events, integrated wind measurements over long path lengths must be obtained. Since direct wind metering devices are point measurement systems, they must be used in an array (Fig. 1). To design and operate an arrayed system in a field environment, unique attributes must be engineered into that system. At present, acoustic or propeller driven anemometers are used to measure direct wind. Since acoustic devices are very expensive from a per unit standpoint ($30,000), they were not considered for use in a multisensor arrayed system. The less expensive propeller driven devices (less than $1,000 each) were chosen as the principal transducer of the system. With this hardware restriction imposed, the field array system should possess the following qualities:

Accurate, reliable measurement of wind velocities

Ability to support a large number of remote units over long path lengths

Interactive operator control and automated operation

High dynamic range and the ability to inhibit ambiguous counts*

Low installation, maintenance, and servicing costs and easy fault analysis

Low battery power consumption at remote units and minimal line installation and maintenance times

Ability to function under severe environmental conditions

Ability to present data in a format suitable for digital analysis

Ability to maintain calibration in hostile environments

*An ambiguous count is induced by shaft oscillations about a point where the oscillations are erroneously interpreted as complete shaft rotation.

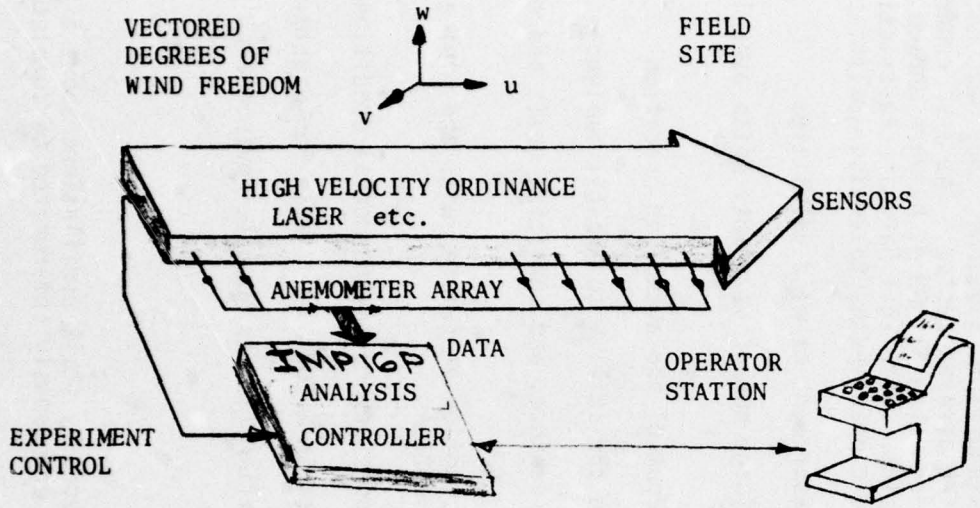


Figure 1. Field operations.

Existing stand-alone propeller driven anemometer systems fall into these two classes:

Analog: wind speed-to-shaft rotation-to-dc voltage conversion

Electro-optical: wind speed-to-shaft rotation-to-electronic pulse conversion.

Analog methods, though low power (i.e., a source rather than sink), are prone to lose calibration, become corrupted with analog noise over long transmission paths, and require multi-input summing amplifiers to process arrayed data or an A/D converter if computer analysis is required. Although capable of maintaining calibration and signal integrity over long path lengths, existing transistor to transistor logic (TTL) electro-optical anemometer methods consume too much power for remote field use (i.e., high power digital logic), do not resolve the ambiguity problem, and require custom communication interfacing if asynchronous array data processing is to be allowed. Therefore, existing systems would not satisfy the previously stated design objectives.

The decision was to design an electronic system which would possess as many of the desired attributes as possible. To expedite the design processes, the mechanical housing, bearing assembly, and propeller of an existing analog anemometer were left intact. The dc motor was replaced with an electromechanical system. The output of the anemometer device was a pulse train in one-to-one correspondence with shaft rotations. Calibration was performed in a low-speed wind tunnel or by use of manufacturer's supplied air screw information. Unlike the analog system, which is prone to lose calibration due to amplifier drift and variability in a long low-grade analog communication channel, the digital system will perform accurately over long periods of time; that is, the anemometer will remain calibrated as long as the propeller and bearing assembly remain structurely unchanged. The electronic signal produced by the new transducer was processed by custom-designed low-power CMOS hardware. The entire system was then interfaced to an asynchronous communication line and microprocessor.

The developed system was capable of supporting up to 128 wind monitoring stations (Fig. 2). Each station consists of battery power supply, electronics, and three orthogonal anemometers (denoted U, V, and W directions). Each remote station was connected to an inexpensive low-grade twisted pair of wires. The line drivers used were rated at 1 Mbit/sec at 2.5 km. The system was controlled through the use of a National IMP-16-P microprocessor.

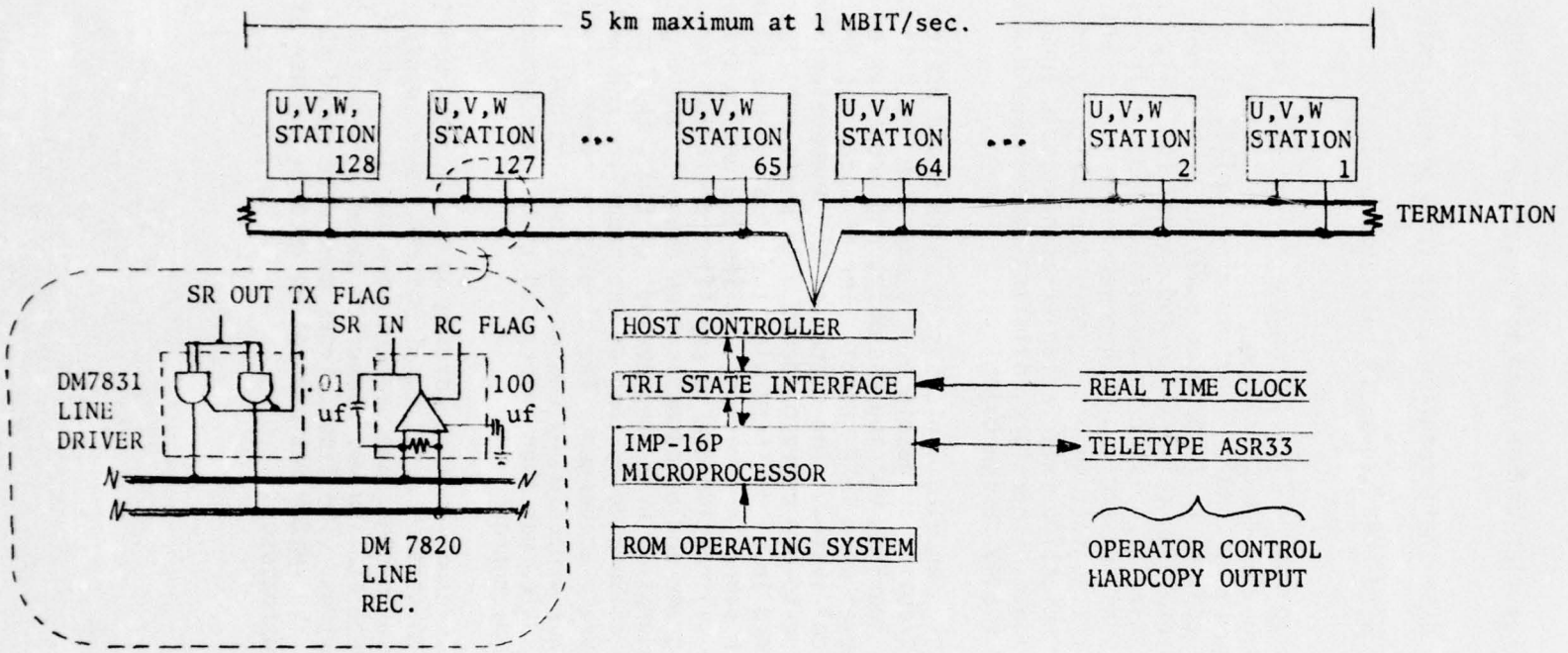


Figure 2. Anemometer array system.

SYSTEM ARCHITECTURE

All point-to-point data and control communication was accomplished through a 20-bit word consisting of 16 bits of information and two start and two stop bits. Conceptually, the developed system functioned as follows:

The pulse train resulting from anemometer shaft rotations, including direction, were shaped, preprocessed (scaled), and presented to an up/down counter.

The up/down counter stored the algebraic count initiated with a system clear-start request. This computer-issued command was received by all remote stations simultaneously.

The remote units were allowed to accumulate data over a user supplied data collection interval. At the end of that interval, a system-wide terminate command was issued to all stations.

The U, V, and W components of any on-line station were then randomly accessed. This initiated a series of events which transferred the appropriate wind component data from the chosen remote station to a custom CMOS asynchronous serial transmitter. The parallel loaded data were then transmitted to the computer for storage and future analysis.

In software, the current and previous counts from a randomly accessed location are differenced. Windspeed can easily be computed from knowledge of the differential count and the averaging interval.

In addition, the current U and V direction counts are compared against 4000_{16}. As long as the U and V counts are below this value, their 16-bit accumulators are assumed to be safe from overflowing during the next averaging interval. If all randomly accessed U and V components pass this test, no system-wide clear command is issued at the end of the data acquisition sequence. The inhibiting of the clear command releases more system time for actual data collecting. If the test fails, a system-wide clear command is issued and counting resumes from zero. Since the 12-bit W component accumulates only extremely low velocity vertical wind information, no overflow sensing software test is provided in this direction.

Figure 3 shows the mechanization of this design philosophy. Certain hardware features of the system, whose implementation is unique to the system developed, will now be investigated in detail.

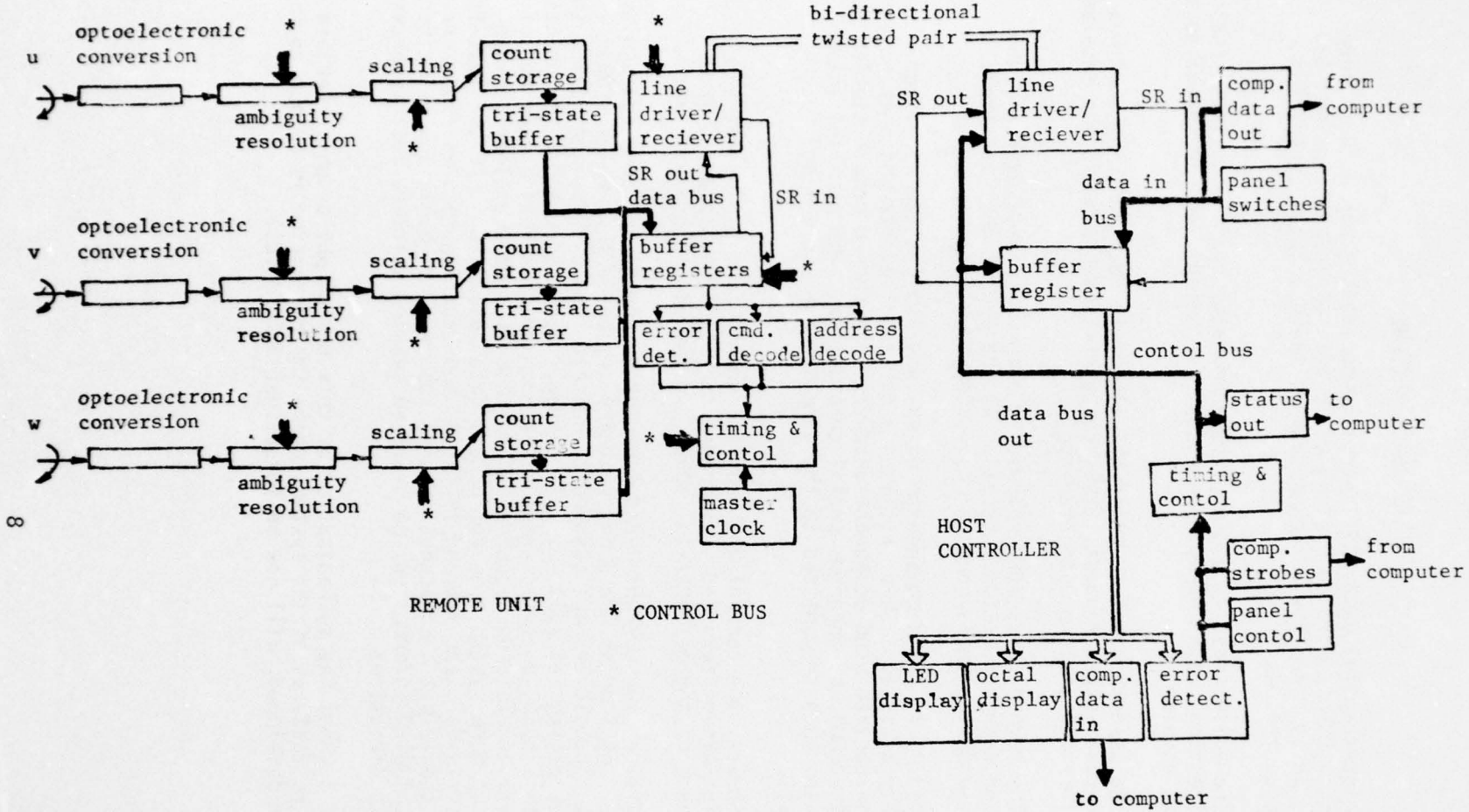


Figure 3. System structure.

Hardware Consideration

Anemometer. Figure 4 shows the developed anemometer (not to scale). The anemometer uses a shaft encoding disk to convert shaft rotations into electronic pulses. The overlaping shots on the disk will create distinctive pulse patterns for clockwise and anticlockwise rotations. The two channels of optically sensed data are presented to the ambiguity resolution circuit (Appendix). The count and sign information created in the ambiguity resolver is sent to the scaling preprocessor.

Scaler. The up/down counter used to accumulate the shaft rotation counts was 16 bits in length in the horizontal U-V directions. Upon computer request, the 16-bit count would be transmitted asynchronously back to the computer. However, under high average wind conditions and long averaging intervals, the up/down counter could easily overflow within an averaging interval. To overcome the problem of inter-interval overflow, a programmed divider, or scaler, was used. The division options are 1, 2, 4, and 16. The user will initially specify a scale factor. During execution, if the data are in danger of causing an overflow within an averaging interval, system software will automatically cause the next largest scale factor to be implemented. Since vertical winds (i.e., W direction) are of low velocity, no scaling hardware was provided for this component.

Timing and Control. The developed system used a 1 MHz CMOS crystal control clock. Sixteen clock pulse were used to define a data bit interval. The resulting 62.5 kHz data rate exceeded an a priori design acquisition rate of 0.5 second per system measurement. The reduced data rate will also allow the system to communicate over lengths in excess of 5 km. If higher data rates were required, a higher master clock rate could be used. However, the increased data rate would result in shorter transmission lengths and increased power requirements (i.e., CMOS power requirements are proportional to speed of operation).

Line Drives. The line drivers used were National 7831 (see the insert diagram of Fig. 2).

Microprocessor. A National IMP-16-P microprocessor was interfaced to the developed system through the use of tri-state logic. The computer controlled the anemometer system through the issuance of scaling, termination counting, clear counters, and data request commands. Each component of wind at each station was assigned a unique random access address. The address was coded on an 8-pole DIP switch. An ASR-33 teletype was used as a hard copy data logger, program input device, and operator console. The operating system can be entered from paper tape or from four 8 by 256 programmable read only memories (PROMS). Figure 5 is a block diagram of the developed data acquisition software system.

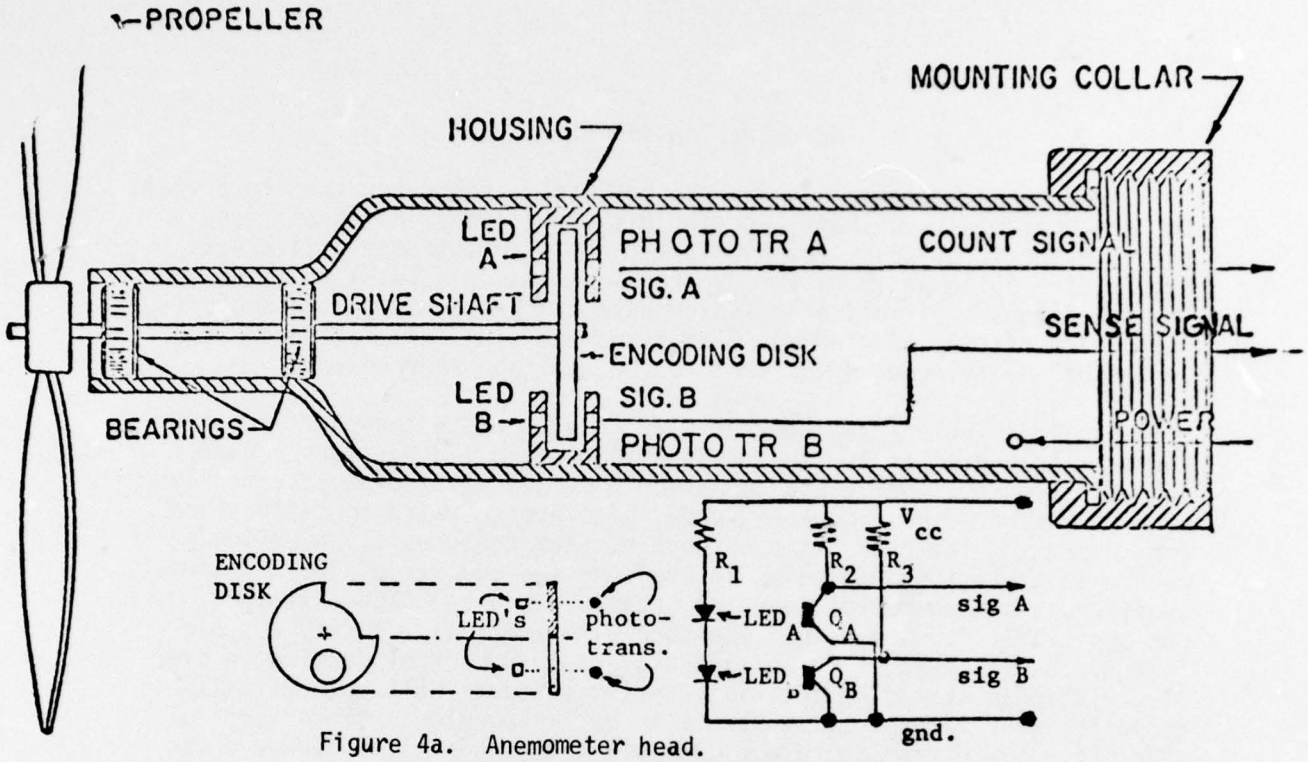


Figure 4a. Anemometer head.

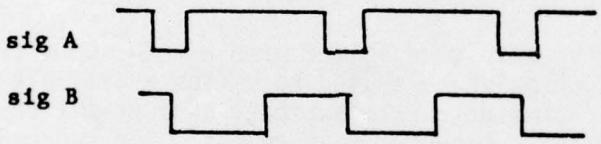


Figure 4b. Clockwise rotation.

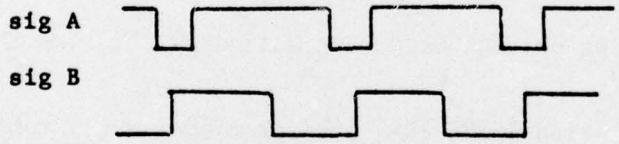


Figure 4c. Anti-clockwise rotation.

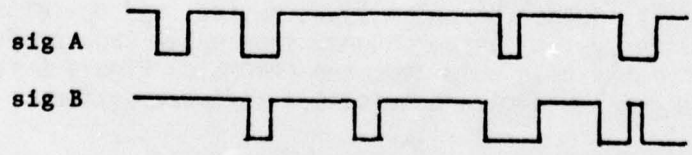


Figure 4d. Ambiguous count.

Figure 4. Opto-electronic conversion system.

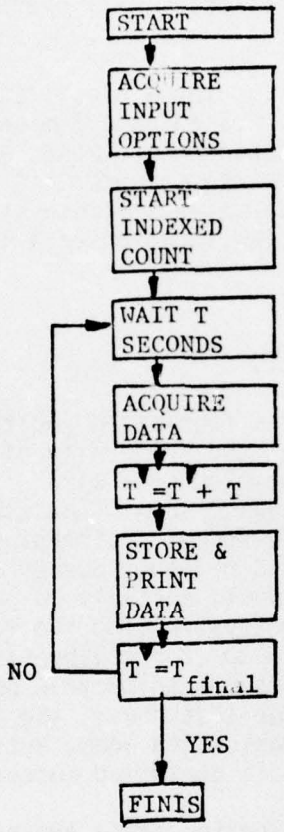


Figure 5. Data Acquisition Program.

OPERATION

Once the system has been field assembled and the operating system loaded, the operator initiates the program. Under the prompting of the computer, the user enters calendar, time of day, averaging interval, total time, and initial scaling information. The system will operate automatically thereafter.

Line fault analysis is performed by issuing a clear, start count, transmit data command to each remote address. Based on a 3 m/sec latency between a start followed immediately by a stop count command, a wind of less than 100 m/sec will return a zero count to the computer. A line fault is indicated by the reception of 17777_8. Since each remote station's position is known on the communication line, the location of a line fault can be easily determined.

RESULTS

A system as described in this work was fabricated and tested at Biggs Army Airfield, El Paso, Texas, and at the University of Texas at El Paso. The remote station was assembled on a wire wrap prototyping board and mounted in a 9 by 9 by 3 chassis box. The computer interface and control was mounted on a 144-socket prototyping I/O card. The system has operated accurately and reliably during the initial test phase. Anemometer calibration would normally be performed in a low-speed wind tunnel. The developed system used the manufacturer's propeller-to-wind speed conversion factor for calibration. The system operated unattended for 30 days with a 6-V motorcycle battery at the prototype remote stations. During the test phase, the ambiguity resolution circuit asynchronous communication loop, automated overflow protection software, and fault analysis performed successfully.

Data samples obtained during the evaluation phase are presented in Figs. 6 through 8. The data are to be interpreted with respect to the following format:

MONTH DAY	##	##	identify
GMT: HRS MINS	##	##	experiment
TOT TM: HR MN	##	##	total time
INTRVL: MN SC	##	##	averaging interval
DIV INDX	##	###	division index
			0000 = ÷ 1
			0001 = ÷ 2
			0002 = ÷ 4
			0003 = ÷ 16
CALIB: +/- ### - ###			(+ or - nominal value)

Data

Hour Minute S = U Component (M/S) S = V Component (M/V) S = W Component (M/S)

where

$$S = a_1\ a_2\ a_3\ a_4\ a_5 = 10a_1 + a_2 + 10^{-1}\ a_3 + 10^{-2}\ a_4 + 10^{-3}\ a_5$$

During the prototype evaluation phase, the U, V, and W channels were driven by a common anemometer. This technique was used because: (1) successful U, V, W operation could be easily verified (i.e., all three channels should present similar data), and (2) it reduced the cost of building a prototype system since only one anemometer needed to be fabricated.

The partial data base presented in Fig. 6 represents the result of a 5-minute experiment using 5-second averaging intervals. Calibration data were supplied from manufacturer's suggestions, and the division index was chosen to be 000 = 1. The wind value was near 3.6 msec. Figure 7 describes another test performed under similar experimental conditions, except the calibration factor was given a positive correction from its nominal value.

The partial data base shown in Fig. 8 represents an experiment with a simulated high wind derived from a 16-inch fan. In the presence of high winds, a division index of 0003 = 16 was chosen. The first test (Fig. 8a) was performed with the anemometer in an upwind position for 5 minutes and the data logged (note the algebraically negative winds). The program was reinitiated with the anemometer in a downwind position. All but the first 5-second data record were positive. The first record was negative because the anemometer was reversed during the first 5-second averaging interval of experiment described in Fig. 8b. The absolute magnitudes of the winds (Figs. 8a and 8b) are different because the anemometer was not in perfect orthogonal up and down wind positions. The data presented in Fig. 9 represent a partial record of a 1-hour 30-second averaging interval experiment performed on 11 November 1975 at Biggs Army Airfield, El Paso, Texas. The average windspeed ranged from 7.616 m/sec at 14 hours 4 minutes 30 seconds GMT to 2.145 m/sec at 14 hours 56 minutes 30 seconds GMT. For demonstration, the rotor was manually blocked and rotated counterclockwise during execution. Figure 9 shows results of these actions.

The W component found at 2 minutes 30 seconds into the experiment is seemingly in error. The negative -38921 count is due to an overflow of the 12-bit W accumulator. No W component overflow protection was provided (see item 5 of the system architecture description) since vertical winds were assumed to be of low velocity. The actual wind

```
MONTH     DAY08  25
GMT:HRS MINS16  30
TOT TM:HR MN00  04
INTRVL:MN SC00  05
DIV INDX: 0000

CALIB:+/-000-000
PRESS RUN!
 00000  05        03569      03569      03569
 00000  10        03505      03441      03505
 00000  15        03505      03569      03505
 00000  20        03633      03569      03633
 00000  25        03569      03633      03569
 00000  30        03505      03505      03505
 00000  35        03505      03505      03505
 00000  40        03569      03569      03569
 00000  45        03633      03633      03633
 00000  50        03505      03505      03505
 00000  55        03633      03633      03633
 00001  00        03633      03633      03633
 00001  05        03505      03505      03505
 00001  10        03633      03569      03633
 00001  15        03505      03569      03505
```

Figure 6. Laboratory experiment.

```
MONTH     DAY08  25
GMT:HRS MINS16  20
TOT TM:HR MN20  08
INTRVL:MN SC00  10
DIV INDX: 0000

CALIB:+/-000+222
PRESS RUN!
 00000  10        03826      03826      03826
 00000  20        03861      03826      03861
 00000  30        03722      03757      03722
 00000  40        03861      03861      03861
 00000  50        03931      03931      03931
 00001  00        03826      03826      03826
 00001  10        03826      03826      03826
 00001  20        03757      03757      03757
 00001  30        03757      03757      03757
 00001  40        03757      03757      03757
 00001  50        03757      03757      03757
 00002  00        03931      03931      03931
 00002  10        03826      03826      03826
 00002  20        03826      03826      03826
 00002  30        03861      03861      03861
```

Figure 7. Laboratory experiment.

```
MONTH     DAY08  25
GMT:HRS MINS20  17
TOT TM:HR MN00  04
INTRVL:MN SC00  05
DIV INDX: 0003

CALIB:+/-000-000
PRESS RUN1
 00000  05      - 38752   - 39771   - 38815
 00000  10      - 37732   - 37732   - 37732
 00000  15      - 37732   - 37732   - 37668
 00000  20      - 36712   - 36712   - 37477
 00000  25      - 37732   - 37732   - 37158
 00000  30      - 37732   - 37732   - 36967
 00000  35      - 36712   - 36712   - 36712
 00000  40      - 36712   - 36712   - 37477
 00000  45      - 36712   - 36712   - 36393
 00000  50      - 36712   - 36712   - 35947
 00000  55      - 36712   - 36712   - 36521
 00001  00      - 35692   - 35692   - 35628
 00001  05      - 36712   - 36712   - 35883
 00001  10      - 37732   - 37732   - 37158
 00001  15      - 36712   - 36712   - 36839
 00001  20      - 36712   - 36712   - 36202
 00001  25      - 36712   - 36712   - 36903


MONTH     DAY08  25
GMT:HRS MINS20  28
TOT TM:HR MN00  04
INTRVL:MN SC00  05
DIV INDX: 0003

CALIB:+/-000+000
PRESS RUN1
 00000  05      - 25728   - 25728   - 45890
 00000  10        32633     32633     32951
 00000  15        32633     33653     32760
 00000  20        30593     30593     30657
 00000  25        31613     31613     31677
 00000  30        31613     31613     31358
 00000  35        30593     30593     30466
 00000  40        30593     30593     30529
 00000  45        30593     30593     30721
 00000  50        29573     29573     29127
 00000  55        29573     29573     30020
 00001  00        30593     30593     30083
 00001  05        28554     28554     29382
 00001  10        28554     28554     28617
 00001  15        29573     29573     29191
 00001  20        28554     28554     29127
 00001  25        29573     29573     29000
 00001  30        28554     28554     28617
```

Figure 8. Laboratory experiment.

```
MONTH     DAY11   19
GMT:HRS MINS13   59
TOT TM:HR MN01   00
INTRVL:MN SC00   30
DIV INDX: 0000

CALIB:+/-0000000
PRESS RUN!
 00000   30          04674       04674       04674
 00001   00          04865       04865       04865
 00001   30          04716       04716       04716
 00002   00          04886       04886       04897
 00002   30          04599       04589     - 38921 *
 00003   00          05715       05725       05715
 00003   30          03409       03409       03409
 00004   00          00000       00000       00000   } ROTOR ROTATION
 00004   30          00000       00000       00000   } STOPPED MANUALLY
 00005   00          00000       00000       00000   }
 00005   30          03845       03845       03845
 00006   00          07616       07616       07616
 00006   30          05162       05162       05162
 00007   00          00000       00000       00000
 00007   30        - 00424     - 00435     - 00424   } CLOCKWISE
 00008   00        - 00435     - 00435     - 00435   } ROTATION CAUSED
 00008   30        - 00424     - 00414     - 00424   } MANUALLY
 00009   00          04379       04079       04079
 00009   30          05226       05226       05226
 00010   00          04737       04727       04737
   :               ~   :       ~   :       ~   :
 00032   00          03802       03802       03802
 00032   30          02379       02379       02379
 00033   00          02676       02676       02687
 00033   30          02443       02443       02443
 00034   00          02591       02591       02591
 00034   30          03293       03293       03293
 00035   00          02953       02953       02942
 00035   30          03441       03420       03441
 00036   00          03909       03930       03919
 00036   30          04886       04886       04875
 00037   00          04206       04206       04206
 00037   30          03335       03335       03335
   :               ~   :       ~   :       ~   :
 00055   30          03399       03399       03399
 00056   00          03633       03633       03633
 00056   30          03378       03378       03367
 00057   00          02273       02273       02273
 00057   30          02145       02145       02145
 00058   00          02698       02698       02708
 00058   30          02889       02889       02889
 00059   00          02825       02825       02825
 00059   30          02698       02698       02687
END
```

Figure 9. Field experiment.

```
MONTH     DAY38  25
GMT:HRS MIN520  10
TOT T.T:HR MN00  07
INTPVL:MN SC00  10
DIV INDX: 0000

CALIB:+/-000-000
PRESS RUN!
 00000  10        03441      03441      03473
 00000  20        03569      03569      03537
 00000  30        03537      03537      03537
 00000  40        03505      03505      03505
 00000  50        03537      03537      03537
**ERROR***
 00001  00      - 17623    - 17623      00000
**ERROR***
 00001  10        00000      00000      00000
 00001  20        29542      29542      11918
 00001  30        03473      03473      03473
 00001  40        03535      03505      03505
 00001  50        03537      03537      03537
 00002  00        03569      03569      03569
 00002  10        03601      03569      03601
 00002  20        03633      03664      03633
**ERROR***
 00002  30      - 17878    - 17878      00000
**ERROR***
 00002  40        00020      00000      00020
 00002  50        29988      29988      12110
 00003  00        03569      03569      03569
 00003  10        03537      03537      03537
 00003  20        03505      03505      03505
 00003  30        03473      03473      03473
 00003  40        03505      03505      03505
 00003  50        03569      03569      03569
 00004  00        03473      03473      03473
**ERROR***
 00004  10      - 21096    - 21096      00000
 00004  20        28968      28968      07671
 00004  30        03569      03569      03569
 00004  40        03537      03537      03569
 00004  50        03537      03537      03537
 00005  00        03505      03505      03505
 00005  10        03537      03537      03537
 00005  20        03601      03601      03601
 00005  30        03441      03441      03441
 00005  40        03409      03409      03409
 00005  50        03537      03537      03537
 00006  00        03505      03505      03505
 00006  10        03505      03505      03505
 00006  20        03601      03601      03601
 00006  30        03505      03505      03505
 00006  40        03569      03569      03569
 00006  50        03537      03537      03537
END
```

Figure 10. Error detection.

count loaded into the W direction accumulator was obtained from the horizontally deployed anemometer. The high count found in this direction caused the W component to overflow before the U and V component overflow test caused a system clear command to be issued.

Figure 3 dramatizes what would occur if a line fault were detected. During execution, a series of line faults were induced and detected, and the event was logged on the teletype. The system will detect absence of count due to remote station failure, noise corrupting framing code, or communication line failure.

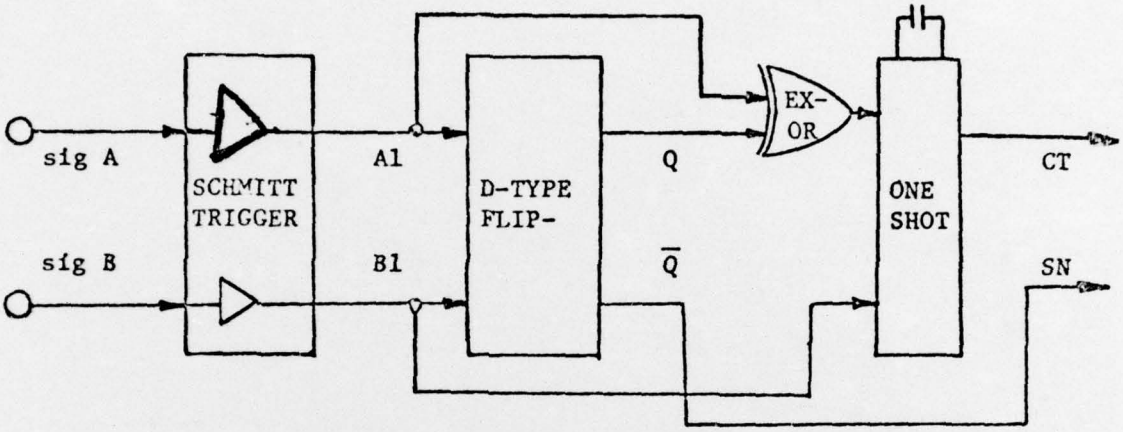
CONCLUSIONS

The developed system satisfies the a priori design criterion. Instrument flexibility was achieved through the use of a microprocessor. The microprocessor capability handled the electronic control and simple data logging responsibilities. It can also serve as a computer and a mass storage device communications controller; therefore, the system can be integrated into a sophisticated meteorological data acquisition system. The system has performed without fault over extended periods of time in both laboratory and field environments. A new feature or modification, the use of a magnetic proximity shaft encoder instead of an LED device, is suggested for inclusion in any production model. This modification and the use of low power MOS line drivers would allow the system to operate at a 25 MW level.

APPENDIX

Ambiguity Resolution Circuit

The ambiguity circuit which inhibits oscillatory shaft fluctuations is described below.



The outputs of the photo-transistors, namely sig. A and sig. B (Fig. 4), are the two inputs to the Schmitt Trigger A (MC14583) which have built-in hysteresis for improved noise immunity. The output A1 is latched into the flip-flop B at the rising edge of A2. The falling edge of A2 is used to trigger the one-shot D(MC14528), which results in a short pulse at the output of the one-shot. However, the output pusle is inhibited if the state of A1 (stored in the flip-flop B) is the same as A1 at the falling edge of A2.

For normal rotation (Fig. 4b or 4c), the one-shot is enabled and a clock pulse results at CT. However, if the anemometer shaft merely oscillates about a point (Fig. 4d), the one-shot is disabled and a no-count results.

The output $\overline{Q}$ of the flip-flop is dependent on the direction of rotation and will be HIGH for one direction and LOW for the other.

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